CLAIMS

What is claimed is:

1. A surface-micromachined fluid-ejection apparatus, comprising:
   (a) a substrate;
   (b) an open-ended cylindrical fluid-ejection chamber formed on the substrate and further comprising a plurality of stacked and patterned layers of polycrystalline silicon, with the fluid-ejection chamber being adapted to receive a fluid, and with the fluid-ejection chamber further having a fluid-ejection orifice formed through a wall thereof at a location distal to an open end of the fluid-ejection chamber; and
   (c) a piston formed on the substrate and moveable in the plane of the substrate from a first position outside the fluid-ejection chamber to a second position inside the fluid-ejection chamber to eject a jet or drop of the fluid through the orifice.
2. The apparatus of Claim 1 further comprising a microelectromechanical actuator formed on the substrate and operatively connected to move the piston between the first and second positions.
3. The apparatus of Claim 2 wherein the actuator comprises an electrostatic actuator.
4. The apparatus of Claim 3 wherein the electrostatic actuator comprises a bidirectional electrostatic actuator to provide a reciprocating motion to the piston.
5. The apparatus of Claim 2 wherein the actuator comprises a thermal actuator.
6. The apparatus of Claim 5 wherein the thermal actuator comprises a bent-beam thermal actuator.
7. The apparatus of Claim 2 further including another microelectromechanical actuator operatively connected to retract the piston after ejection of the fluid.
8. The apparatus of Claim 1 wherein the substrate comprises silicon.
9. The apparatus of Claim 1 wherein the piston comprises polycrystalline silicon.
10. The apparatus of Claim 1 further including a fluid reservoir in fluidic communication with the fluid-ejection chamber for providing the fluid thereto.
11. The apparatus of Claim 10 wherein the fluid-ejection chamber includes an opening through a sidewall thereof to provide a pathway for the fluid to enter the fluid-ejection chamber.

12. The apparatus of Claim 11 wherein the sidewall of the fluid-ejection chamber is hollow and forms a fluid communication channel between the fluid reservoir and the fluid-ejection chamber.
13. The apparatus of Claim 10 further including a fluid fill port formed through the substrate for supplying the fluid to the fluid reservoir.
14. The apparatus of Claim 10 wherein the piston is located, at least in part, inside the fluid reservoir, and the actuator is located outside the fluid reservoir.
15. The apparatus of Claim 14 wherein the piston is connected to the actuator by a linkage which penetrates through an opening in a sidewall of the fluid reservoir.
16. The apparatus of Claim 15 wherein the opening in the sidewall of the fluid reservoir further includes an indentation opposite each side of the linkage to provide a gas-bubble seal between the linkage and the fluid reservoir to limit a leakage of the fluid through a gap separating the linkage and the opening in the sidewall of the fluid reservoir.
17. The apparatus of Claim 15 further including means for collecting any leakage of the fluid through a gap separating the linkage and the opening in the sidewall of the fluid reservoir.
18. The apparatus of Claim 17 wherein the means for collecting the leakage comprises a duct extending outward from the gap for conducting any leakage of the fluid away from the gap.
19. The apparatus of Claim 18 wherein the duct empties into a fluid evacuation port formed through the substrate.
20. The apparatus of Claim 18 wherein the duct empties into a fluid evaporation tank formed on the substrate.
21. The apparatus of Claim 1 wherein the fluid-ejection orifice has a diameter of 50 microns or less.
22. The apparatus of Claim 1 wherein the fluid-ejection chamber comprises an electric-field-free region, with the piston and fluid-ejection chamber both being maintained at a ground electrical potential during ejection of the jet or drop of the fluid.

23. A surface-micromachined fluid-ejection apparatus, comprising:

(a) a substrate;

(b) an open-ended fluid-ejection chamber formed on the substrate from a plurality of stacked and patterned layers of polycrystalline silicon, with the fluid-ejection chamber being adapted to receive a fluid, and with the fluid-ejection chamber further having a fluid-ejection orifice formed through a wall thereof;

(c) a fluid reservoir formed on the substrate from the plurality of stacked and patterned layers of polycrystalline silicon and connected to the fluid-ejection chamber to supply the fluid thereto;

(d) a piston formed on the substrate and moveable in the plane of the substrate to eject a jet or drop of the fluid through the fluid-ejection orifice; and

(e) at least one microelectromechanical actuator formed on the substrate and operatively connected to provide reciprocating motion to the piston, with the microelectromechanical actuator being located outside the fluid reservoir and outside the fluid-ejection chamber.

24. The apparatus of Claim 23 wherein a fluidic connection between the fluid reservoir and the fluid-ejection chamber is provided through the piston.

25. The apparatus of Claim 24 wherein the fluidic connection comprises a hollow portion of the piston and a flapper valve formed within the piston.

26. The apparatus of Claim 23 wherein a fluidic connection between the fluid reservoir and the fluid-ejection chamber is provided through a hollow sidewall of the fluid-ejection chamber.

27. The apparatus of Claim 23 wherein a fluidic connection between the fluid reservoir and the fluid-ejection chamber is provided through a spacing between the piston and an open end of the fluid-ejection chamber when the piston is in a retracted position.

28. The apparatus of Claim 23 wherein a mechanical connection between the microelectromechanical actuator and the piston is made through an opening in the sidewall of the fluid reservoir.

29. The apparatus of Claim 28 wherein the opening in the sidewall of the fluid reservoir further includes an indentation opposite each side of the linkage to provide a gas-bubble seal between the linkage and the fluid reservoir to limit a leakage of the fluid through a gap separating the linkage and the opening in the sidewall of the fluid reservoir.
30. The apparatus of Claim 28 further including means for collecting any leakage of the fluid through a gap separating the linkage and the opening in the sidewall of the fluid reservoir.
31. The apparatus of Claim 30 wherein the means for collecting the comprises a duct extending outward from the gap for conducting any leakage of the fluid away from the gap.
32. The apparatus of Claim 31 wherein the duct empties into a fluid evacuation port formed through the substrate.
33. The apparatus of Claim 31 wherein the duct empties into a fluid evaporation tank formed on the substrate.
34. The apparatus of Claim 23 wherein the substrate comprises silicon, and the piston comprises polycrystalline silicon.

35. A surface-micromachined fluid-ejection apparatus, comprising:

(a) a substrate;

(b) an open-ended fluid-ejection chamber formed on the substrate, with the fluid-ejection chamber forming an electric-field-free region whereby a fluid disposed therein is not contacted by any electric field produced by the apparatus, and with the fluid-ejection chamber further having a micron-sized fluid-ejection orifice formed through a top wall thereof;

(c) a fluid reservoir formed on the substrate and connected to the fluid-ejection chamber to supply the fluid thereto;

(d) a piston formed on the substrate and moveable in the plane of the substrate to eject a portion of the fluid through the fluid-ejection orifice; and

(e) at least one microelectromechanical actuator formed on the substrate outside the fluid reservoir and operatively connected to provide reciprocating motion to the piston.

36. The apparatus of Claim 35 wherein the substrate comprises monocrystalline silicon, and each of the fluid-ejection chamber, the fluid reservoir, the piston and the microelectromechanical actuator comprise polycrystalline silicon.

37. The apparatus of Claim 35 wherein the piston is connected to the microelectromechanical actuator by a linkage which penetrates through an opening in a sidewall of the fluid reservoir.

38. The apparatus of Claim 37 wherein the opening in the sidewall of the fluid reservoir further includes an indentation opposite each side of the linkage to provide a gas-bubble seal between the linkage and the fluid chamber to limit a leakage of the fluid through a gap separating the linkage and the opening in the sidewall of the fluid reservoir.

39. The apparatus of Claim 37 further including means for collecting any leakage of the fluid through a gap separating the linkage and the opening in the sidewall of the fluid reservoir.

40. The apparatus of Claim 39 wherein the means for collecting the leakage comprises a duct extending outward from the gap for conducting any leakage of the fluid away from the gap.
41. The apparatus of Claim 40 wherein the duct empties into a fluid evacuation port formed through the substrate.
42. The apparatus of Claim 40 wherein the duct empties into a fluid evaporation tank formed on the substrate.